SCIENCE FOR GLASS PRODUCTION

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PRODUCTION OF FLOAT GLASS EXCEEDING THE EQUILIBRIUM IN THICKNESS (REVIEW)

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A classification of methods of production of thick float glass using restriction of lateral spreading of the glass melt in the initial part of the melting tank is developed. Brief descriptions of patented methods are provided. The main methods developed by the Saratov Institute of Glass in the field of production of clear and tinted heat-absorbing glass exceeding the equilibrium in thickness are described.

The Saratov Institute of Glass started research in the field of float-glass production in 1973. This was motivated by increasing demand for polished glass 8 – 30 mm in thickness for shop-window glazing, glass door plates, structural optics, and other purposes.

The existing facilities could not satisfy the need for thick glass, and the challenge of that period was to develop a highly efficient production technology for high-quality thick glass by using the method of continuous molding of glass ribbon over a metallic melt.

An analysis of the regularities of spreading of glass melt over the melted-metal surface and experiments performed at the Institute revealed that glass ribbon whose thickness exceeds the equilibrium should be produced by restricting lateral spreading of the glass melt in the front part of the melt tank with subsequent intense cooling of the ribbon in order to retain the thickness attained.

An analysis of current international technologies for production of thick float glass also indicated predominant use of this method.

A review of published sources revealed leading patenting trends in production technologies for glass exceeding the equilibrium in thickness and made it possible to classify the patented techniques and installations.

The classification presented in Scheme 1 shows that lateral spread of glass melt can be restricted by mechanical means, the use of gas, liquids, or specific temperature conditions, or a combination of the latter with mechanical means. The mechanical means in turn can be mobile or immobile or be a combination of both types.

The variety of techniques limiting the lateral spread of glass melt is caused by the search for optimum conditions for thick-glass molding, since in order to obtain high-quality glass, it is necessary to ensure uniform and symmetric advance of the glass-ribbon edges that come in contact with the limiters. Failure to meet this requirement causes increased variation in the ribbon thickness. If the ribbon edges move more slowly than the ribbon middle, the edge portions of the ribbon will be thinner than the middle, and when the right and left edges move at different speeds, the lateral profile of the ribbon will be wedge-shaped. Adhesion of the glass-ribbon edges to the limiters produces stagnation areas in which the glass melt starts crystallizing, which makes the process unstable.

Let us discuss in more detail the methods for limiting the side spreading of glass melt described in patents.

Let us begin with mechanical means that are most widely patented. According to the classification developed they can be subdivided into immobile (patent numbers: Gr. Britain 1112071, 1270933, 1421910; USA 3846102, 3846108, 401438; France 1426918, 1539127), mobile (France 1580650; USA 3684471; Gr. Britain 976693, 1226648, 1223525), and a combination of both (Gr. Britain 1122871, France 157894, 2351916).

Immobile limiters are special bars usually made of a material not wettable by the glass melt, which most often is graphite.

In one of the variants the immobile limiters are placed parallel to the melt tank walls after the restricters. The limiters form a channel for the glass-melt flow (Fig. 1) The width of the channel depends on the prescribed width of the ribbon,

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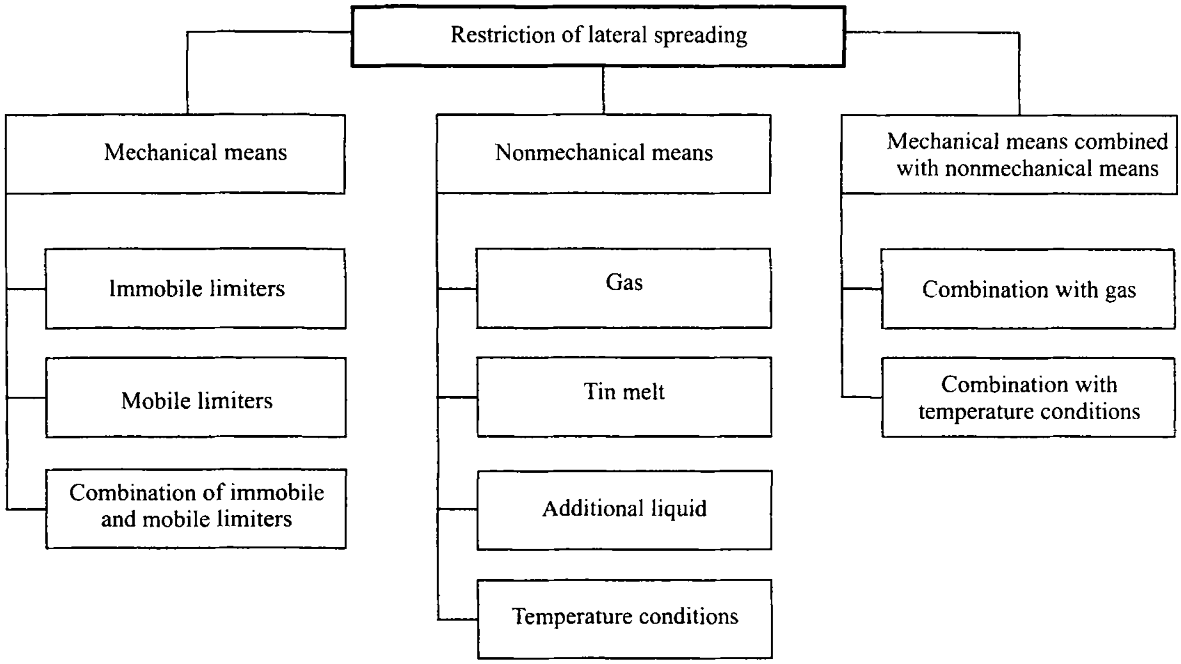
Scheme 1. Classification of Methods and Devices for Production of Thick Float Glass



its thickness, the speed of release of the finished ribbon from the tank, and the amount of glass melt fed. The length of the limiters should be sufficient for the glass melt to solidify and retain the required geometric dimensions before it leaves the space between the limiters. The limiters are cooled by water circulating inside pipes that are components of the limiters.

In another variant, the immobile limiters abut the open ends of the restricters and are likewise placed parallel to the melt tank walls (Fig. 1). The immobile limiters are hollow bodies consisting of a bottom wall and side walls forming one or several cavities that are filled with a ballast, for instance, melted tin, in order to adjust the limiter immersion depth.

A necessary condition for production of thick glass with high quality parameters, in particular, high accuracy of thickness, is equal speed of movement of the edge areas and the middle portion of the glass ribbon.

This problem is solved by applying pulling forces to the upper or side surface of the glass-ribbon edges, i.e., by using mobile limiters to which the required speed is imparted.

An example of this is a method in which lateral spreading of the glass melt is restricted by a rotating vertical disk partly immersed in the tin melt and equipped with a roller whose projections set in motion the glass-ribbon edges through contact of the roller with the upper surface of the ribbon edges (Fig. 2).

The disks and the rollers are made of a material that does not stick to hot glass or of metal that is cooled by water or another liquid fed along the shaft supporting the limiter. The shaft is set in motion by a motor that can adjust the rotational speed of the disks and the rollers.

In another variant that is quite common, in particular on Pilkington float lines, the lateral spreading of the glass melt is restricted by toothed rolls that come in contact with the upper surface of the ribbon edges. The rolls are usually made of metal and cooled with water. The rotational speed of the rolls is adjusted by a motor.

Another technique for restriction of the lateral spreading of glass melt by mobile limiters consists in imparting vibrations of various frequency and amplitude to the limiters. This completely prevents adhesion of the glass ribbon to the elements restricting its width, and since in this case there is no need to cool the limiters, the speed of advance of the ribbon edges is virtually equal to the speed of its central part. Figure 2 shows a way of restricting the lateral spreading of glass melt by limiters equipped with pushers.

Let us consider a combination of mobile and immobile limiters for thick-glass molding. The lateral spreading of the glass melt in this case is restricted by water-cooled immobile limiters that form a channel inside the melt tank along which the glass ribbon moves. To provide unobstructed movement of the ribbon edges, an additional pulling force that facilitates their advance at the required speed and is applied to the upper surface by edge rolls is developed (Fig. 3).

Other methods for restricting the lateral spreading of glass melt in production of glass whose thickness exceeds the equilibrium involve the use of nonmechanical means, namely, gas (patent: France 1461220), jets of melted tin (France 2064357), an additional liquid (Gr. Britain 1109392), or specific temperature conditions (Gr. Britain 1302772).

The restriction of spreading of glass melt using gas consists in continuous supply of pressurized gas from the lateral walls of the tank toward the glass-ribbon edges (Fig. 4*a*). This produces a gas layer between the surface of the lateral walls of the tank and the glass-ribbon edges, which prevents their contact.

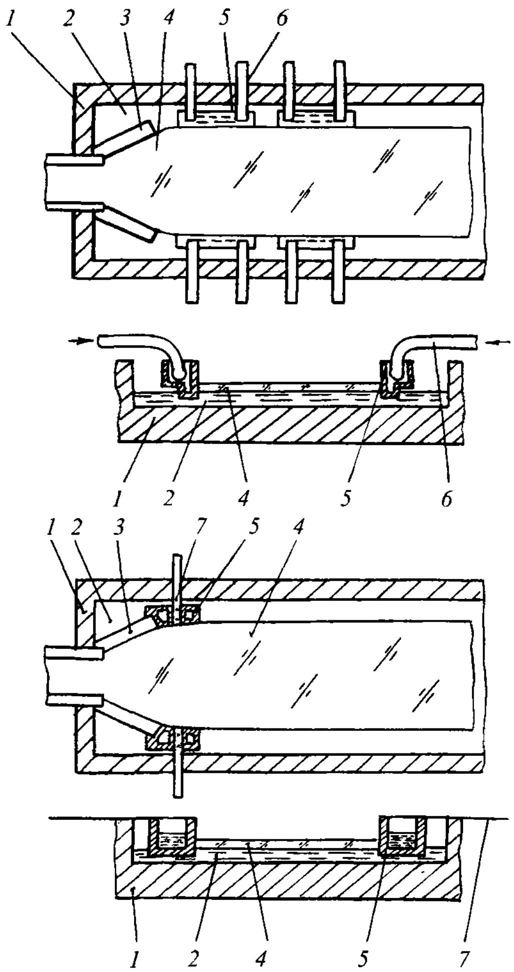


Fig. 1. Restriction of lateral spreading of glass melt by immobile limiters: *1*) melt tank; *2*) tin melt; *3*) restricters; *4*) glass ribbon; *5*) limiters; *6*) water-cooling pipes; *7*) clamps holding the limiter.

Another example of restricting the lateral spreading of glass melt by nonmechanical means involves the use of melted-tin jets directed toward the glass-ribbon edges by special nozzles placed under the glass ribbon (Fig. 4*b*). Acting upon the lateral edges of the ribbon, the melted-tin jets restrict lateral spreading of the glass melt and ensure the required conditions for molding a glass ribbon that exceeds the equilibrium in thickness.

Another method for restricting the lateral spreading of glass melt consists in placing a special liquid in the space between the glass-ribbon edges and the lateral walls of the melt tank (Fig. 4*c*). The parameters of the liquid density and the interphase tension with respect to the gas medium, the tank wall material, and the glass melt should ensure the possibility of controlling the glass-melt thickness. Here the liquid does not flow under the glass, and the glass melt does not flow under the liquid. The liquid should be chemically inert to the glass, the tank wall material, and the protective atmosphere of the tank.

Another patented method for restricting the lateral spreading of glass melt involves maintaining special temperature conditions, namely, differentiated cooling of the middle and edges of the glass ribbon in the molding zone (the temperature of the ribbon middle is maintained at the level of 900 – 1050°C, and the temperature of the edges is within the limits of 650 – 800°C). For this purpose, special longitudinal bottom partitions are set in the tin under the glass-ribbon edges.

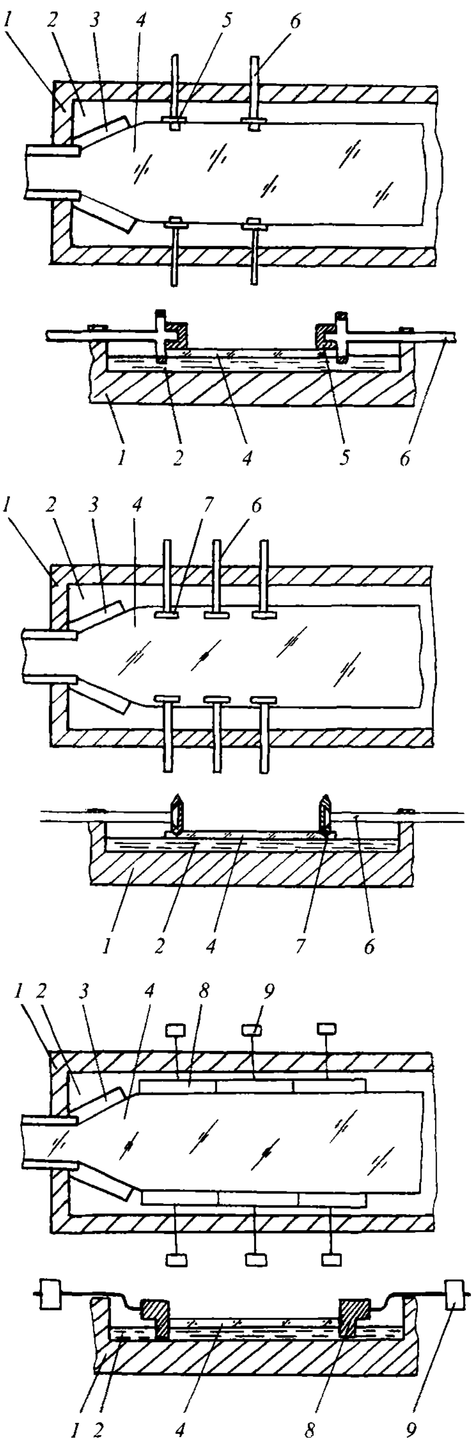


Fig. 2. Restriction of lateral spreading of glass melt by mobile limiters: *1*) melt tank; *2*) tin melt; *3*) restricters; *4*) glass ribbon; *5*) water-cooled disks with rollers, *6*) water-cooling pipes; *7*) water-cooled rolls; *8*) limiters; *9*) vibration generators.

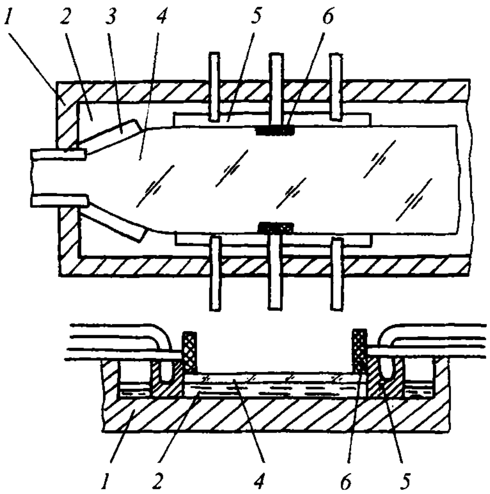


Fig. 3. Restriction of lateral spreading of glass melt by a combination of mobile and immobile limiters: *1*) melt tank; *2*) tin melt; *3*) restricters; *4*) glass ribbon; *5*) water-cooled immobile limiters; *6*) water-cooled edge or toothed rollers with hatching.

Finally, some methods for restricting the lateral spreading of glass melt include both mechanical and nonmechanical means.

A widely used patented method provides for the use of both immobile limiters and gas fed between the working surfaces of the limiters and the glass-ribbon edges (patents: Gr. Britain 1230480, 1222240; France 1535006, 1354805, 2132625). In this combination, the immobile limiters prevent lateral spreading of the glass melt, and the gas prevents adhesion of the ribbon in the course of its advance. Gas can be supplied through special slots or directly through the porous refractory material of which the part of the limiter immersed in the tin is made (Fig. 5).

Some methods of thick-glass production concern the use of immobile limiters in combination with temperature conditions that provide more intense cooling of the glass-ribbon edges compared to its middle (patents: France 1426918, 235116).

As a consequence of the patent analysis conducted and the developed classification, it was established that most patents are related to restriction of lateral spread of glass melt by mechanical means (mobile and immobile limiters or a combination of them), which indicated that this direction is promising with respect to its practical application.

In 1973 – 1979 the Saratov Institute of Glass carried out research, design, and development work that resulted in several methods for thick-glass production, including patent-cleared ones (USSR Inventor's Certif. 485078, 511299, 537040, 668239, 440348, 566782).

The first method consisted in molding with the use of water-cooled limiting elements in combination with rotating screws (Fig. 6*a*). At the beginning of the molding zone the glass-melt flow was restricted laterally by water-cooled immobile graphite limiters that abutted the elongated restrictors. After the ribbon left the area where spreading was restricted by the water-cooled limiters, its width and thickness were controlled by rotating graphite screws fixed on water-cooled axes. The screws either were partly immersed in the melt and made contact with the glass-ribbon edges (Fig. 6*b*) or engaged the upper surface of the glass-ribbon edges

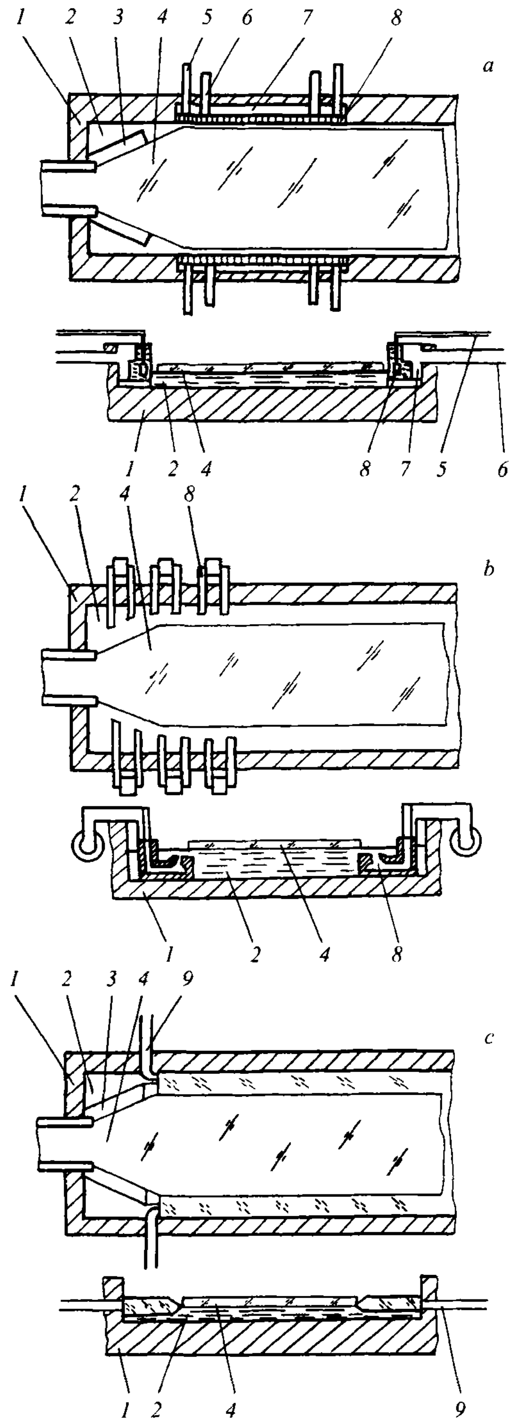


Fig. 4. Restriction of lateral spreading of glass melt by gas (*a*), melted-tin jets (*b*), and an additional liquid (*c*): *1*) melt tank; *2*) tin melt; *3*) restricters; *4*) glass ribbon; *5*) gas-supply connection; *6*) water-cooling pipes; *7*) porous wall of the melt tank; *8*) tin

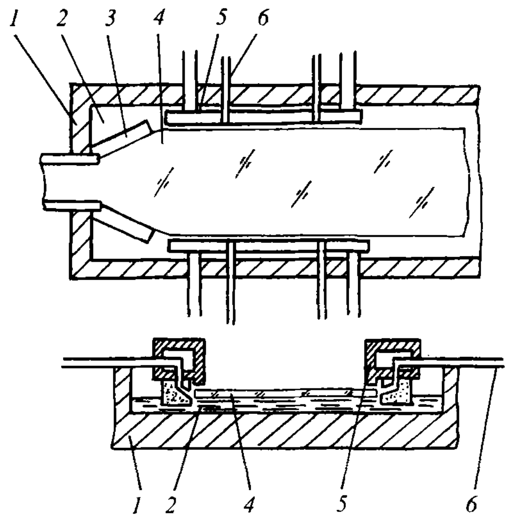


Fig. 5. Restriction of lateral spreading by immobile limiters with gas lubrication: *1*) melt tank; *2*) tin melt; *3*) restricters; *4*) glass ribbon; *5*) water-cooled immobile limiters; *6*) gas supply point.

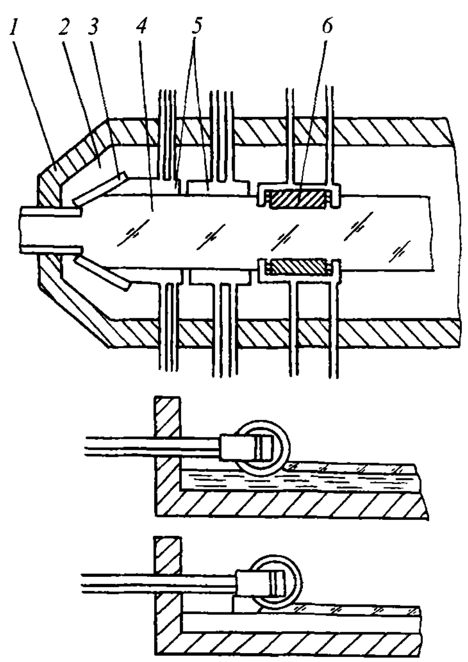


Fig. 6. Restriction of lateral spreading by immobile limiters in combination with screws: *1*) melt tank; *2*) tin melt; *3*) restricters; *4*) glass ribbon; *5*) water-cooled immobile limiters; *6*) screws.

(Fig. 6*c*). In order to prevent the glass melt from spreading substantially after contact of the ribbon with the screws ended, the melt was cooled intensely by rhombic roof chillers.

This method ensured production of thick glass with the required quality parameters, and yet due to the relative complexity of the screw control it was not recommended for industry. The next stage involved development and testing of another design of mobile limiters, namely, caterpillar mechanisms installed in a water-cooled casing. Their working parts

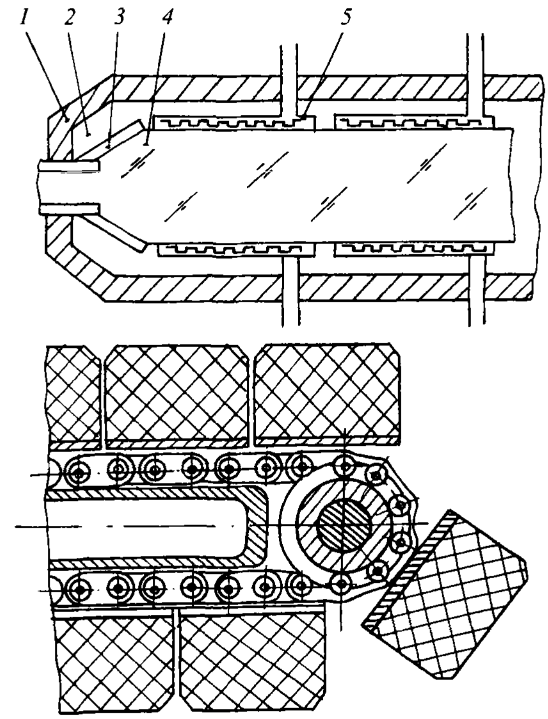


Fig. 7. Restriction of lateral spreading of glass melt by caterpillar mechanisms: *1*) melt tank; *2*) tin melt; *3*) restricters; *4*) glass ribbon; *5*) caterpillar mechanisms.

comprise a chain conveyer, which is set in motion by an electric motor, and graphite shoes fastened on the chain links (Fig. 7).

The caterpillar shoes were partly immersed in the tin melt and thus restricted lateral spreading of the glass melt and at the same time accompanied the glass-ribbon edges at the prescribed speed. The mechanisms were placed after the restricters in the molding area along the melt tank walls. The distance between the rows of caterpillar shoes was set equal to the width of the glass ribbon produced, and the speed of their movement was selected approximately equal to the glass-melt speed in the given area.

The caterpillar machines proved to be more convenient in service, and therefore, the technology of thick-glass production with the use of these devices was constantly upgraded.

At present a process for molding glass 8 to 12 mm thick involving the use of caterpillar machines has been developed.

In addition to the methods mentioned above, the Institute developed other methods for thick-glass production. They include, for example, the use of mobile limiting elements that perform reciprocating motion at a sharp angle to the direction of glass-ribbon movement and push away the ribbon edges, which prevents its lateral spreading (Fig. 8*a*), or mobile limiters that are periodically brought into contact with the glass-ribbon edges and move in the direction of drawing with subsequent removal from contact (Fig. 8*b*), and others.

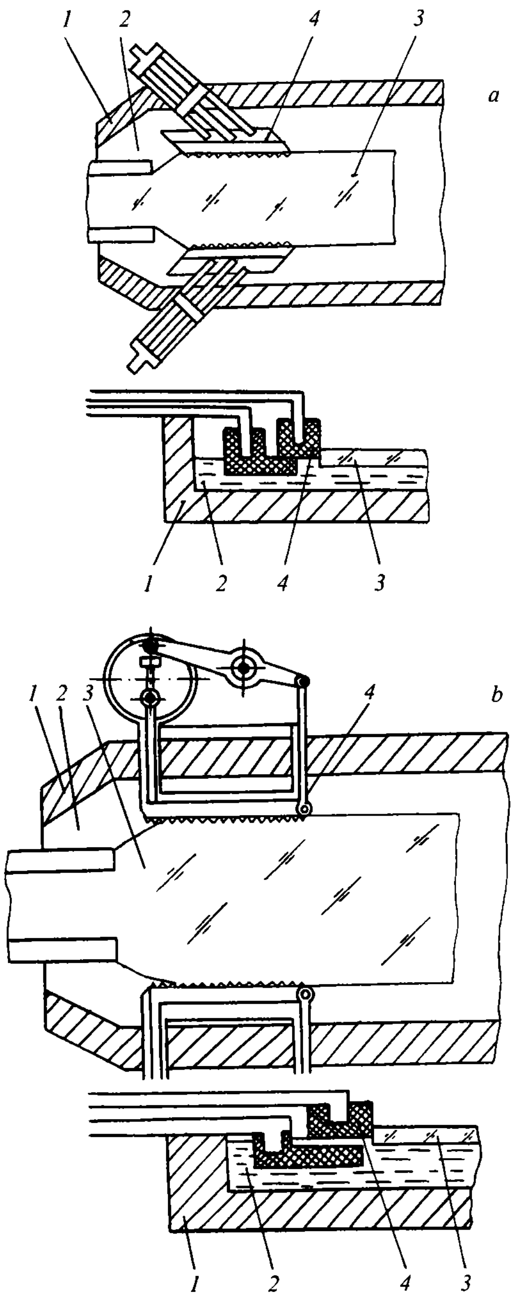


Fig. 8. Restriction of lateral spreading of glass melt by mobile limiters that perform reciprocating motion at an angle to the direction of drawing (*a*) and are periodically brought into contact with the glass-ribbon edges (*b*): *1*) melt tank; *2*) tin melt; *3*) glass ribbon; *4*) mobile limiters.

In 1973 – 1982 researchers of the Institute developed methods, equipment, and technology for molding glass whose thickness exceeds the equilibrium, which made it possible to produce high-quality glass 8 – 12 mm thick and satisfy the demand for thick glass. The main contribution in this field was made by M. L. Glikman, V. M. Sizov, A. G. Shabanov, E. B. Fainberg, N. A. Kapkov, L. Ya. Povitkova, and V. V. Bezlyudnyi.

The overall production of glass 8 – 12 mm thick on the ÉPKS-4000 line between 1976 and 1978 amounted to 170,000 m^2. The quality parameters of this glass for the most part met the requirements of the TU 21-23-12-97–75 and TU 21-54-21–77 standards in force. The glass was used for doors, shop windows, and structural-optics products.

Since in 1979 the ÉPKS-4000 line was converted to the manufacture of heat-absorbing glass (of bluish-green shade), which differs from ordinary clear glass in viscosity and crystallization properties, researchers of the Institute refined and corrected the parameters of the technology of thick-glass production.

In subsequent years the ÉPKS-4000 line was used to produce bluish-green heat-absorbing glass. 180,000 m^2 of thick glass meeting the requirements of TU 21-54-44–79 was produced up to1982.

The next stage in the upgrade of the technology of thick-glass production was related to conversion of the ÉPKS-4000 line to the manufacture of bronze-colored heat-absorbing glass, including glass 8 – 10 mm thick, which was caused by the growing demand for tinted glass with special light and thermal properties in both the CIS and foreign countries. Tinted thick glass is now widely used as glazing in shop windows, windows, balcony enclosures, glass furniture, and glass prefab structures (diners, pavilions, etc.). Moreover, the need for a new technology of thick-glass production was determined by increased quality requirements, in particular, as concerns the thickness precision parameter, which depends on the conditions for glass-ribbon molding.

The use of previously developed thick-glass technologies did not allow achievement of the required glass quality. This was due to the fact that heat-absorbing tinted glass has different temperature-viscosity parameters, namely, the viscosity of this glass changes over a narrower temperature interval, which calls for a shorter molding zone.

At present the Institute has developed a new production technology for high-quality heat-absorbing tinted glass whose thickness exceeds the equilibrium, and it is the leading domestic producer in this field. The method envisions the creation of special conditions in the glass-melt outflow unit that make it possible to mold a plane-parallel profile of the thick glass ribbon, and subsequent variation of the technological parameters and the operating conditions of special equipment allows production of the prescribed width and thickness of the ribbon. Thick glass produced according to the new technology meets requirements of the TU 21-05524989-186–97 standard.

Between 1992 and 1997, 340,000 m^2 of glass 8 – 10 mm thick was produced and successfully marketed. In addition, experimental batches of glass 12 mm thick were manufactured.

Thus, the Saratov Institute of Glass JSC currently possesses production technologies for both clear and tinted light- and heat-shielding float glass whose thickness exceeds the equilibrium. The Institute continues research in this area intended to implement technologies of thick-glass production on industrial float lines.